Aerosols attenuating the solar radiation collected by solar tower plants: the horizontal pathway at surface level

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1. Impact of the aerosols on the attenuation

Solar Thermal Energy plants (STE) use solar radiation as primary source of energy, concentrated on a single focus point, the optical receiver (***Fig. 1***). The distance between the optical receiver and a heliostat can be larger than 1 km, and the attenuation of the reflected solar beam at surface level becomes not negligible. Such attenuation impacting directly the production of the STE, its precise estimation is relevant in the development phase of a STE.

It is though more difficult to infer what occurs at surface level (below 200 m height) than across the whole atmosphere (***Fig. 2***). How to provide the best estimate of the attenuation at surface level ? This is the objective of the ASoRA project to propose several methods. One method is applied here, using the aerosol optical thickness (AOT) measured by AERONET and the boundary layer height (BLH) provided by ECMWF, with a potential application on satellite remote sensing data for generating regional maps of surface level attenuation.

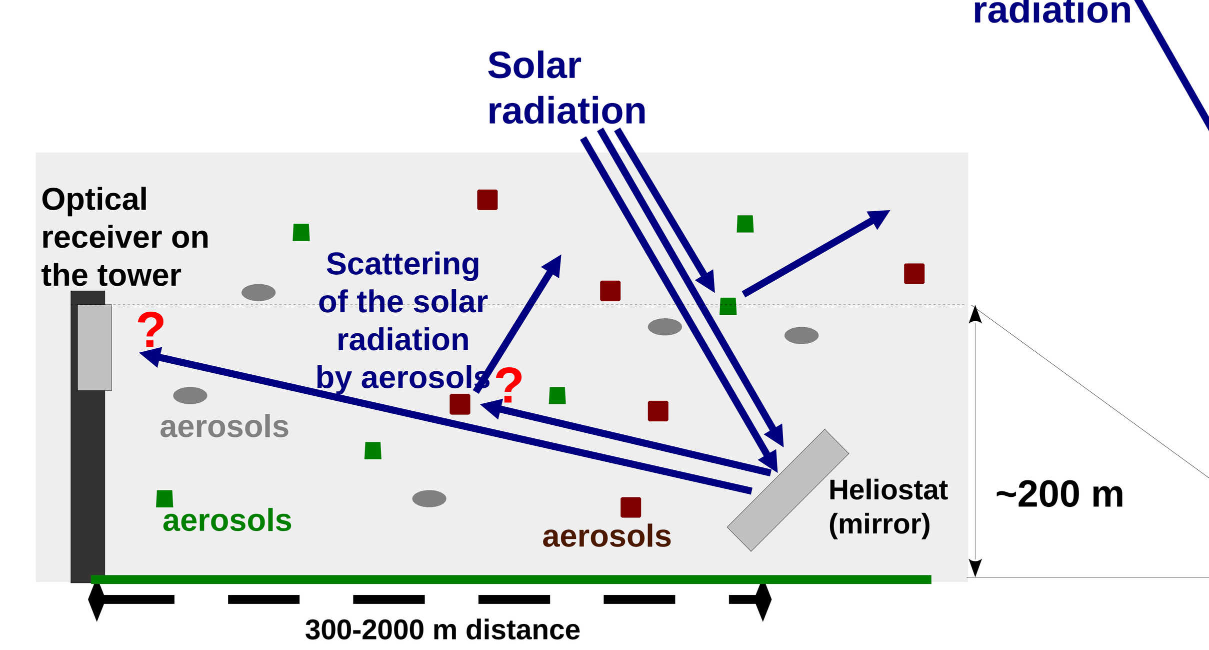

Figure 1. *Schematic view of the two optical pathways in a STE, and the scattering effect by aerosols, which is investigated here between the heliostat and the tower.*

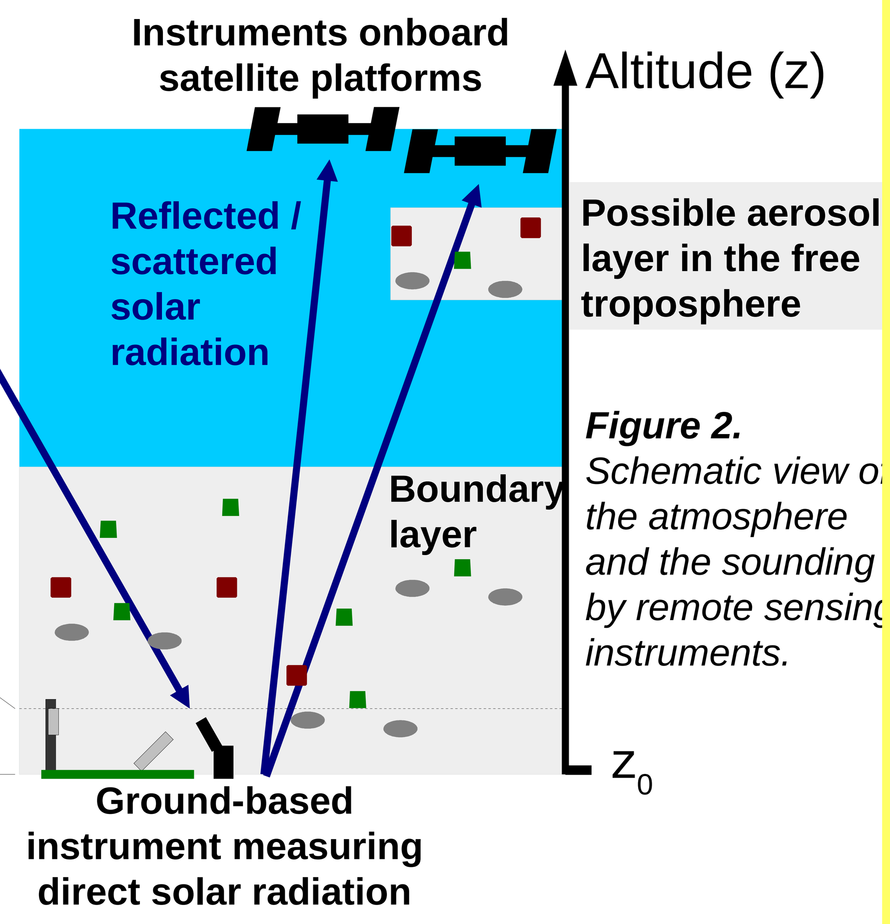

Figure 2. *Schematic view of the atmosphere and the sounding by remote sensing instruments.*

2. Method

Most variability of the atmospheric attenuation is caused by changes in aerosol concentration, properties and spatial distribution. Aerosols are consequently the main source of uncertainty of the atmospheric attenuation estimate.

Measurements are made by the AERONET[1] network to follow the impact of aerosols on solar radiation at high temporal and horizontal resolutions. AERONET provides aerosol properties integrated over the atmospheric column, as the aerosol optical thickness (AOT), while we need the aerosol extinction coefficient at surface level (AEC(z_0)):

$$AOT = \int_{z_0}^{TOA} AEC(z)\,dz$$

The equation is simplified by making the hypothesis of a uniform and unique aerosol layer fitting the boundary layer:

$$AEC = AOT / BLH$$

Figure 3. *Sun photometer of the AERONET network.*

AERONET measurements are dedicated to aerosol investigation and are made in several aerosol spectral windows where gases do not absorb the solar radiation. The spectral dependence of estimated attenuation depends on aerosol size and on Rayleigh scattering, negligible at wavelength larger than 700 nm but significant in blue spectrum. Variability at time scales of the year and the month are computed, at 4 wavelengths.

3. Validation

Measurements were made during the **SAMUM** field experiment in May-June 2006 in Morocco[2]:

AOT = 0.32 by AERONET

AEC = 100±50 Mm^{-1} by lidar[3]

Aerosol layer height (ALH) = AOT / AEC = **3.2 km**

The month averages of BLH derived by ECMWF for the operational analysis at 12-15:00 varied between **2.9±0.7 and 3.6±0.7 km**.

VALIDATED at Ouarzazate (Morocco)

Measurements were also made during the **AMMA** field experiment at Banizoumbou[4]:

ALH = **3.7±1.9 & 2.6±1.4 km** in January & February 2006, while BLH = **1.4±0.3 & 1.7±0.3 km**.

NOT VALIDATED at Banizoumbou (Niger)

ALH≠BLH

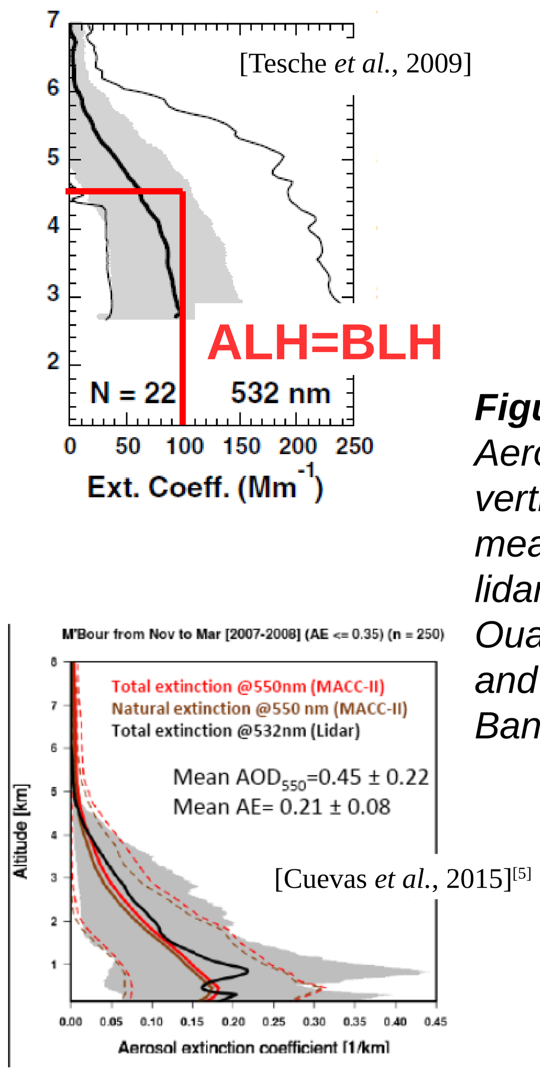

Figure 4. *Aerosols vertical profiles measured by lidar above Ouarzazate and Banizoumbou.*

The approach is not validated at Banizoumbou because several aerosol layers are observed while only one layer is observed above Ouarzazate (***Fig. 4***).

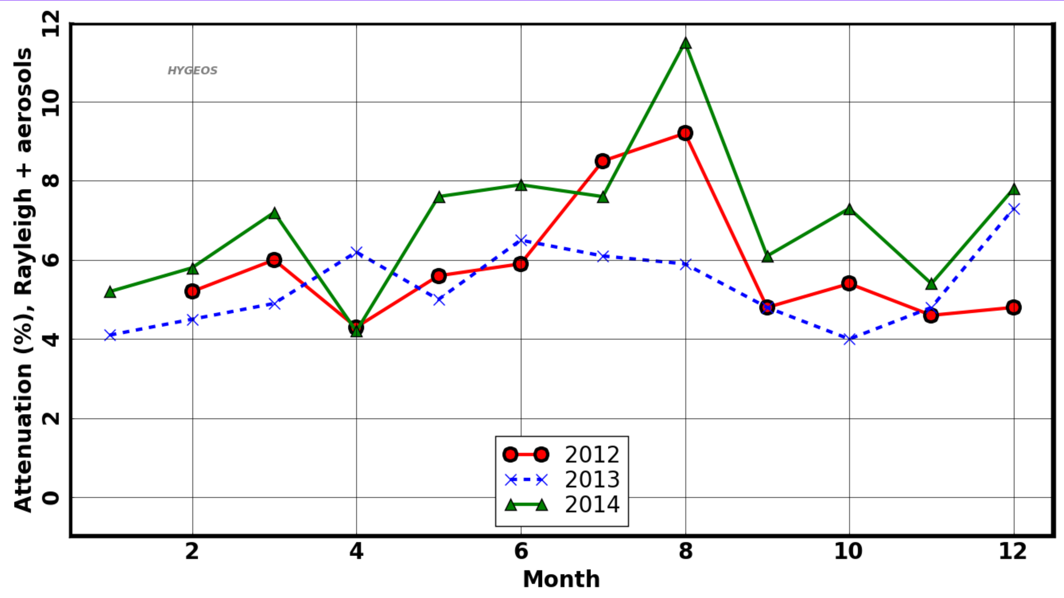

Figure 5. *Monthly averages of the attenuation at 500 nm at Ouarzazate, derived from AERONET and ECMWF/BLH.*

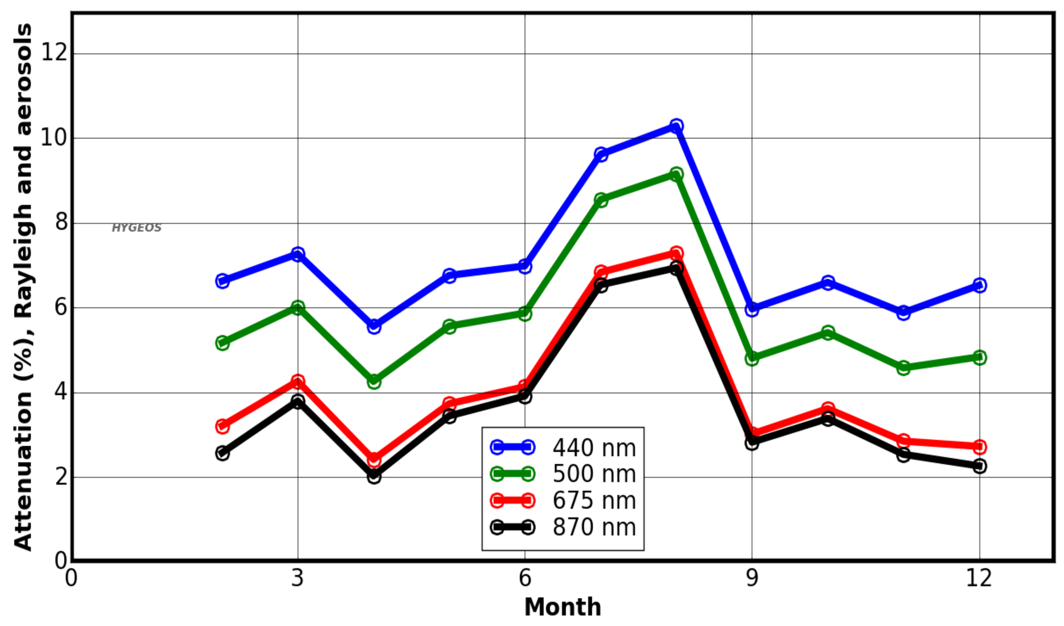

Figure 6. *Monthly averages of the attenuation at several wavelengths in 2012 at Ouarzazate (AERONET, level 1.5).*

4. Estimated attenuation

Attenuation at surface level caused by molecules (Rayleigh) and aerosols is computed for a heliostat-receiver distance of 1 km. The attenuation is highly variable, from less than 4% in winter 2013 to more than 8% in summer 2012 and 2014, at 500 nm (***Fig. 5***). Desert dust events generate a significant magnitude in the annual cycle. Indeed AOT increases by a factor 5 from winter-spring to summer, which is partly compensated by a simultaneous increase of BLH. AOT usually starts to increase in May and maximum is usually reached in August.

Variability is also important between two years (***Fig. 5***), with a mean annual attenuation of 4.8% in 2013 and 6.2% in 2012. It is also observed at a monthly time step, as in May with 4.2% in 2013 but 7.5% in 2014 (***Fig. 5***).

The variability also depends on the wavelength. The attenuation decreases with increasing wavelength, while the variability increases (***Fig. 6***). Indeed the attenuation increases by a factor of 3 from winter to summer at wavelengths larger than 675 nm.

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